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COMPOSTED MUNICIPAL REFUSE AS A SOIL AMENDMENT

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problems involved in solid waste management, this report, published by the National Environmental Research Center - Cincinnati, evaluates the use of processed residential refuse from four municipal composting plants as a source of plant nutrients and as a soil amendment.

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Director
National Environmental Research Center

ABSTRACT

Processed residential refuse from four municipal composting plants was evaluated as a source of plant nutrients and as a soil ammendment. Indicator plants were turnip (Brassica rapa L.), pearl millet (Pemnisetum typhoideum L., Rich.), cranberry beans (Phaseolus vulgaris Savi), tomato (Licopersicon esculentum Mill.), and sorghum (Sorghum vulgare Pers.). Three of the composts used were high in carbon and low in nitrogen which resulted in delayed nitrification accompanied by poor plant growth. Total soluble salts in those composts were relatively high and could affect seed germination. Extracts of compost (160 g/500ml H_2O) greatly reduced germination in radish and turnip seed and extracts from 320 g compost/500 ml H_2O reduced germination to 0 in turnip and radish seed and to about 40 percent in oat and millet seed. After a period of time in the soil, compost applications above 32 metric tons/ha increased plant yields and improved soil cation exchange capacity and water-holding capacity

In laboratory studies with compost incorporated at various levels in Arredondo sand, almost no nitrification occurred. When mixed with cow manure in equal parts compost effectively curtailed nitrification in the cow-manure almost 100 percent. Fungi in compost/soil mixtures increased greatly as did bacteria; however, bacterial numbers decreased rapidly after 4 or 5 days.

COMPOSTED MUNICIPAL REFUSE UTILIZED AS A SOIL AMENDMENT

C. C. Hortenstine and D. F. Rothwell

INTRODUCTION

The handling, processing, and disposal of solid waste have reached such proportions in the United States that solid waste management is one of the major pollution problems today. The citizens of the United States discard over 200 million tons of solid waste annually (about 6 pounds/person/day). In the past, most of this waste was burned in open dumps or deposited in mismanaged landfills. Because of air and water pollution, more satisfactory methods must and are being developed for solid waste disposal. Composting with efficient machinery under sanitary conditions shows promise in helping to solve this problem.

Composting municipal waste under controlled conditions is advantageous from several viewpoints, i.e., (1) it makes salvaging of paper and metals feasible, (2) it decreases air and water pollution, (3) there is no health hazard due to fly or rodent populations, and (4) the composted material may be utilized as a soil improving amendment However, the history of composting refuse in the United States shows that most such operations started optimistically and failed dismally. Usually the cause of failures can be traced to the instilled philosophy in municipal officials that a saleable product can be made from a waste material. It should be recognized that the refuse comes in as a waste product and it must leave as a waste product.

The ancient Romans recognized the value of turning under legumes for soil enrichment. Nitrate accumulation in the soil as a result of organic matter

decomposition was known to European agriculturists over 300 years ago. However, it was not until late in the 19th century that the role of bacteria in nitrogen fixation began to be understood by microbiologists. In 1886, Hellriegel and Wilfarth proved that legumes fixed nitrogen in the atmosphere through the action of nodule bacteria. Beijerinck isolated the responsible organisms (Rhizobium) in 1888.

The value of composting animal and plant residues for subsequent soil applications to improve productivity has been recognized for a 100 years or more. During the composting procedure carbon is used as an energy source by microorganisms with release of CO_2 into the atmosphere. As the process continues, plant nutrients are concentrated and made more available. Certain conditions are essential for proper composting: (1) optimum moisture, aeration, and temperature: (2) an adequate supply of soluble nitrogen; and (3) a neutral or slightly alkaline pH. It is usually desirable to add nitrogen and phosphorus in order to accelerate the decay process in compost piles.

Compost can be made from any carbonaceous material insofar as the conditions outlined above are met. Generally, composts are prepared from plant tissues which contain relatively low percentage of plant nutrients. A combination of plant and animal wastes will usually yield an ideal compost, However, animal manures are not generally available and the average gardener must relie on chemical mixtures containing the desired nutrients.

Soil and plant scientists have studied the composting of various plant residues and the availability of the plant nutrients contained in the finished compost, and, generally, reported favorable results. Martin and Wang[18] compared composts prepared from cornstalks, oat straw, salt-grass hay, leaves, and cow manure. Compost prepared from cornstalks and inorganic salts was superior in all comparisons to the other composts, and composting was complete

in 70 days with cornstalks as compared to 110 days with other materials. Fatty and waxy compounds were almost completely broken down in all materials composted. Cellulose decomposition varied from 83 percent in oat straw and clover hay to 92 percent in cow manure. Hemi-cellulose decomposition varied from 66 percent in oat straw plus chemicals to 82 percent in cow manure. Lignin changes varied from a gain of 7 percent in cornstalks plus chemicals to a loss of 55 per cent in leaves plus timothy hay. The composts were mixed with Penn loam soil at the rate of 50 tons per acre and used in greenhouse experiments with tomatoes, barley, and carrots. The composts prepared from cornstalks plus chemicals and cow manure were superior to 1 ton per acre of 5-10-10 fertilizer where tomato plant yields were compared. Barley responded well to residual cow manure, oat straw plus clover hay, cornstalks plus chemicals, and oat straw plus inorganic salts. Cornstalks and cow manure produced larger yields in the third crop planted, carrots, as compared to the other composts.

In Florida, Smith and Thornton[33] prepared composts from water hyacinths, pine needles, and spanish moss. In each instance, comparisons were made between the materials alone and materials fortified with inorganic or other organic compounds. Water hyacinths produced a superior compost and the nitrogen was readily available. Pine needles did not compost satisfactorily and the nitrogen was relatively unavailable. Spanish moss was not a good material for composting. All materials produced better compost when fortified with additional chemicals or organic materials.

Pain[24] compared mulberry leaf compost with farmyard manure in producing mulberry leaves which served as silkworm (Bombyx mori L.) food. Mulberry leaf compost produced equal yields of comparative nutritional value and the manure and both materials were much more superior to the control (no soil additive) treatment. Composted horse manure serves almost exclusively as the growth

medium for commercial mushroom production; however, Block et al.[4] used a sawdust compost to produce equal or higher yields of mushrooms (Agarius conpestris and Pleurotus ostreatus) as compared to yields from horse manure.

Municipal refuse is highly variable with respect to point of origin, day of collection, and season of the year. According to Bell[2], municipal refuse contained 47 percent cellulose, sugar, and starches. Rogus[28] reported that New York refuse in 1939 contained by weight an average 43.0 percent ashes, 21.9 percent paper, 17.0 percent garbage, 6.8 percent metal, 5.5 percent glass, 2.6 percent wood, and 3.2 percent misc. In contrast, Chicago refuse in 1957 contained 51.5 percent paper, 16.7 percent ashes, 15.5 grass, 7.3 percent metal, 6.0 percent glass, and 3.0 percent garbage. This denoted a considerable drop in ashes and garbage with a large increase in paper. The compostable materials were about 45 percent in 1939 and 70 percent in 1957. However, the increase was mainly in the form of paper which is highly carbonaceous and almost void of nitrogen.

Composting municipal refuse has not received the attention nor popularity in the United States that it has in Europe, the Netherlands and Germany particularly. The compost has received wide acceptance among farmers in those countries as it is used extensively to increase crop yields and improve soil conditions. Tietjen[34] reviewed municipal composting in the German cities of Baden-Baden, Heidelberg, and Kreuznack and cited research results which indicated beneficial effects on water-holding capacity and erosion prevention in soils through the use of the compost. Grape, potato, wheat, oat, rye, and sugar beet yields were also increased where compost was applied to the soil.

In the United States, published research results where composted municipal refuse was evaluated were almost non-existent until recent years. Fuller et al.[10]

grew horticultural plants in the greenhouse where the growth media were soil: compost mixtures of varying ratios and obtained growth responses to the compost. Conover and Joiner[9] obtained earlier flowering of chyrsanthemums by 33 to 50 percent additions of garbage compost to sand. A greater number of flowers was also produced by plants grown in compost amended soil.

The presence of phytotoxic substances in plant residues is well documented[5, 6, 11, 15, 16, 19, 21, 25]. One of the earliest workers, Collison[8], described a toxic effect from aqueous extracts of wheat straw on barley seedlings wherein the roots were discolored, slender, and abnormally curved. The toxin was removed entirely by boiling or filtering through a porcelain filter and greatly reduced by suspending carbon block or ferric hydroxide in the extract. Patrick et al.[26] found substances in decomposition residues of barley, wheat, and sudangrass that were toxic to lettuce, bean, broccoli, and tobacco seed germination. Bieber and Hoveland[3] showed that a phytotoxic substance in water extracts of several weed species interfered with crown vetch seed germination. Nordstadt and McCalla[22] induced phytotoxicity in soil by adding wheat straw to the soil.

In the United States, we are faced with the ever increasing problem of solid waste disposal and agricultural scientists must answer the questions as to the effects on soil and plant life after final deposition. As Scott[31] emphasized, "The inescapable facts are:

"1. That the amount of refuse which has to be disposed of annually ad infinitum keeps increasing.

"2. That whatever the means of disposal practiced-controlled tipping, incineration or composting-a very large proportion of the wastes must go back into or onto the land.

"3. That the capacity of the land to receive these wastes is limited and wasting.

"4. That disposal of refuse is a costly business."

The objectives of these studies were (1) to evaluate composted municipal refuse as a source of plant nutrients, (2) to determine the effects of adding composted municipal refuse to the soil on water-holding capacity, cation exchange capacity, pH, conductivity, extractable plant nutrients, etc., (3) to determine if phytotoxic substances were present in composted municipal refuse, and (4) to determine the effects of adding composted municipal refuse to the soil on microbial activity, in particular, on nitrification and carbon dioxide evolution. Part of this report, which is reported herein under Largo Compost, was published previously [12, 13, 29].

MATERIALS AND EXPERIMENTAL METHODS

Largo Compost

Greenhouse. Composted municipal refuse used in this experiment was obtained from an industrial composting plant which was under contract to compost the refuse from Largo, Florida. Chemical analyses of the compost are shown in Table 1. As obtained from the plant, the compost was 44 percent H_2O on a wet weight basis (79 percent H_2O dry weight basis). The compost was air dried and screened through hardware cloth with 6 mm openings prior to use.

In order to determine the effects of compost on germination, varying amounts (0, 10, 20, 40, 80, 160, and 320 g) of compost were shaken in 500 ml of distilled H_2O for 1/2 hour and filtered. The extracts were stored at 7 C until used. At that time, filter paper discs set in petri dishes were soaked with 5 ml of the extract and the dishes were arranged in randomized blocks

of four replications. Twenty-five seeds of oats (Avena sativa L.,'Suregrain'), turnip(Brassica rapa L., 'Purple Top White Globe'), and pearl millet (Pennisetum typhoideum L., Rick. 'Gahi') were planted on filter paper. After 5 days at 21 C, each group of seedlings was removed, counted, and measured from plumule tip to radicle tip. The filter paper and extracts were renewed between each species planted.

Leon fine sand was air-dried, screened, and limed at the rate of 4 metric tons/ha. Soil and garbage compost were thoroughly mixed in a twin-shell blender and the mixtures were put into plastics pots (2,600 cu cm volume) and arranged in randomized blocks with four replications. Oats, turnips, radishes, and pearl millet were planted consecutively, thinned to a uniform stand, and water was replenished daily weight. Oat foliage was cut at 5 weeks, turnip and radish at 6 weeks, and millet at 10 weeks. Between each crop, the soil was screened to remove roots and repotted.

The Leon soil series belongs to the Spodosols Order, more commonly referred to as Ground-Water Podzols[32]. The most distinguishing feature of Leon soils is a prominent spodic horizon (organic pan) within a depth of 76 cm. The Spodosols comprise 3,737,443 hectares (9,235,223 acres), or 26.60 percent of Florida's land area. Under proper water and fertility managemant, these soils are used profitably for vegetable, citrus, and livestock agriculture. The Leon fine sand used in this experiment had a pH 4.4 and contained 85 ppm Ca, 30 ppm Mg, 13 ppm K, and 2 ppm P.

Plant tissue was dried at 70 C, weighed, and ashed at 500 C for chemical analyses. Nitrogen was determined by the micro Kjeldahl method, P was determined colorimetrically,and K was determined by flame photometry[4]. Soil was sampled after the millet plants were harvested, air dried, and extracted with NH_4OAc (pH 4.8) for Ca, Mg, P, and K determinations[23].

Cation exchange capacity (CEC) was determined by the NH_4OAc method, soil pH was determined in a 1:1 soil: water mixture, and total soluble salts (TSS-mmhos X 640)were determined by electrical conductance in a saturated soil extract[14]. Water-holding capacity was determined by the pressure membrane technique of Richards[27].

Field. This experiment was conducted in 17.6-liter crocks(hereafter referred to as pots) set in the soil. The bottom of each pot was covered with a 2-inch layer of gravel which was, in turn, covered with a layer of glass-wool upon which the treated soil used in the experiment was placed. A glass-wool plug inserted in the drainhole and in contact with the surrounding soil allowed free drainage through the pots. Individual treatments of garbage compost, sewage sludge, cow and chicken manures, and 10-10-10 fertilizer were mixed in a motor-driven cement mixer with 13.7 kg of Leon fine sand which was limed at the rate of 4,5000 kg/ha. Treatments were arranged in the pots in randomized blocks with four replications. Fifty oat seeds (Avena sativa 'Suregrain') were planted in each pot and two cuttings of oat foliage were harvested. After the oat roots were removed, radish (Raphanus sativus 'Early Scarlet Globe') seeds were planted and the seedlings were thinned to 24 per pot when 10 days old.

The organic materials used in this experiment were commercial products except for the garbage compost which was obtained from a composting plant in Largo, Florida. All materials were air-dried and ground to pass a 20-mesh screen before incorporation into the soil. Laboratory analyses of organic materials are presented in Table 1. The high salt content of all materials shown would indicate a possible danger to salt-sensitive plants

if excessive amounts of these materials were applied to the soil, especially where rainfall was not sufficient to carry the salts below the root zone.

Plant material was dried at 70 C, weighed, and ashed at 500 C for chemical analyses. Nitrogen was determined by the micro Kjeldahl method, P and B were determined colorimetrically, K was determined by flame photometry[14] and the other plant nutrients (Ca, Mg, Cu, Mn, and Zn) were determined by atomic absorption[6].

After the radishes were harvested, soil samples were removed from each pot, air dried, and screened through a 0.5 mm sieve for chemical analysis. Soil pH was determined in a 1:1 soil:water mixture, total soluble salts were determined by electrical conductance in a saturated soil extract, cation exchange capacity (CEC) was determined by the NH_4OAc method, and soil Ca, P, K, and Mg were determined in an NH_4OAc (pH 4.8) soil extract. Soil water-holding capacity was determined as moisture equivalent (ME) which is the ability of a soil to hold water under a centrifugal force 1,000 times that of gravity[7].

Microbiological. The surface (0-to-15-cm) layer of an Arredondo fine sand was used for all decomposition studies. The soil had been planted to agronomic crops for many years and had pH 6.4. Nitrification had been previously demonstrated to occur in this soil. The Arredondo soil had not been classified in the new comprehensive system, but will probably be included with the Quartzipsamments.

Organic materials used in these experiments were garbage compost, chicken manure, cow manure, and sewage sludge. All materials except the garbage compost were obtained from local commercial sources. Garbage compost was obtained from a composting plant in Largo, Fla. These organic materials (Table 1) were dried at 70 C and ground in a Wiley mill to pass

a 20- mesh screen. Each material was mixed with soil at specified ratios and moisture adjusted to 100 millibars of water suction. The amended soil was then incubated at 28 C. Evolved CO_2 was absorbed in standard NaOH solution and precipitated as $BaCO_3$ by addition of sufficient $BaCl_2$ solution to insure complete precipitation. Excess NaOH was titrated with standard HCl. Carbon dioxide evolution was determined throughout the various studies. The amounts obtained were added to the previous evolution and reported as totals. Phenolphthalein was used as the indicator. Nitrate-nitrogen was determined by the phenoldisulfonic acid method [14].

The influence of garbage compost on numbers of soil microflora was investigated by mixing 0, 1, 5, and 10 g of compost with 100 g of soil and incubating for 26 days at 28 C. Plate counts, in quintuplicate, were made periodically for relative numbers of fungi on rose bengal agar and for bacteria on soil extract agar [1].

Garbage compost, cow manure, chicken manure, and sewage sludge were used as amendments to Arredondo fine sand at 0, 2, 4, 6, 8, and 10 g per 100 g of soil, replicated three times. The amended soil was incubated for 65 days. Carbon dioxide evolution was determined throughout the study and NO_3-N was determined at the end of 65 days.

Ground garbage compost was also used at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 g per 100 g of soil and incubated for 101 days. Carbon dioxide evolution was determined at various intervals during the investigation.

Another study was conducted to investigate the influence of mixing garbage compost with other organic materials. In this study, garbage compost was mixed with cow manure, chicken manure, and sewage sludge in equal amounts by weight and added to the soil at levels of 0, 1, 2, 3, 4, and 5 g of each

material per 100 g of soil and incubated for 64 days. Carbon dioxide evolution was determined periodically and NO_3-N was determined at the end of the experiment.

St. Petersburg Compost

Greenhouse. A commercial product packaged from composted municipal refuse under the tradename of "Cura" was obtained from the compost plant at St. Petersburg, Florida, for this experiment. The compost (Table 1) was mixed with Arredondo sand which had pH 5.8 and contained 12 ppm P, 28 ppm K, 388 ppm Ca, and 72 ppm Mg. The soil was limed at the rate of 2 metric tons/ha and weighed into portions of 4,500 g each. The soil was mixed thoroughly with compost at rates which progressed geometrically from 1 metric ton/ha through 64 metric tons/ha, placed in pots, and arranged in completely randomized blocks of four replications in the greenhouse. Two control treatments which contained no added fertilizer or a 10-10-10 fertilizer applied at 1 metric ton/ha were used for comparison. The total number of treatments was nine. The soil was wet thoroughly with distilled water and allowed to drain for two days. The pots were weighed and an average weight was obtained as a guide for watering throughout the experiment.

Cranberry beans (Phaseolus vulgaris Savi) were planted, thinned to three plants per pot at 14 days from planting, and harvested at 45 days from planting. Oats (Avena sativa L.) were planted in the pots, after the beans were removed, and harvested at 70 days from planting. Additional fertilizer and compost were applied at the original rates to the appropriate pots, and three 14-day old tomato (Licopersicon esculentum Mill.) seedlings were transplanted from vermiculite into each pot. Two of these plants were

harvested at 14 days from transplanting and the remaining plant was harvested at 56 days from transplanting.

The plant tissue was dried at 70 C, weighed, ground to pass a 20-mesh screen, and analyzed chemically. The soil was sampled after the tomato plant harvest and analyzed chemically.

Fairfield Compost

Greenhouse. A pelletized compost manufactured by the Fairfield Engineering Company, Marion, Ohio, was obtained for this experiment. Arredondo sand with pH 6.6 and containing 11 ppm P, 12 ppm K, 565 ppm Ca, and 6 ppm Mg was weighed in 6,000 g portions and mixed with compost (Table 1) at rates of 8 to 64 metric tons/ha. Again, control treatments with no added fertilizer or 2 tons/ha of 10-10-10 fertilizer were used as comparisons. Sorghum (Sorghum vulgare Pers.) seeds were planted, thinned to four plants per pot at 14 days from planting, and harvested at 70 days from planting. Compost and fertilizer were added again at the original rates to the appropriate pots, sorghum seeds planted, thinned to 6 plants per pot, and harvested at 45 days from planting.

Plant tissue was dried at 70 C, weighed, ground to pass a 20-mesh screen, and analyzed chemically. Soil has not been analyzed as of this report.

Gainesville Compost

Field. Compost prepared by the Gainesville Municipal Waste Conversion Authority, Gainesville, Florida, was used in this experiment. The compost (Table 1) was applied to plots (3 x 7 meters) located on phosphate sand

tailings at International Minerals and Chemical Corporation, Bartow, Florida. The experimental design was a 5 x 5 latain square with treatments as follows:

(1) 1 ton/ha of 10-10-10 fertilizer, (2) 35 tons/ha of compost + 10-10-10, (3) 70 tons/ha of compost + 10-10-10, (4) 35 tons/ha of compost, and (5) 70 tons/ha of compost. Compost and fertilizer were applied in the spring of two consecutive years and sorghum was planted. Sorghum was harvested, fertilizer only reapplied at 1 ton/ha, and oats were planted in the fall of the two years. Plant yields, tissue analyses, and soil analyses were recorded as in other experiments.

RESULTS AND DISCUSSION

Largo Compost

Greenhouse. The specific conductance of the water extracts increased greatly as the amount of compost extracted increased -1.97, 3.50, 5.85, 11.00, 18.00, and 26.60 millimhos per cm for the 10, 20, 40, 80, 160, and 320 g samples, respectively. According to Jackson[14], above 8 millimhos/cm is considered a strongly saline solution and only tolerant plant species will grow satisfactorily in a soil that produces an extract of this concentration or higher.

Of the plant species chosen for this study, turnip has good salt tolerance[20], oat and pearl millet plants have moderate salt tolerance[17]. The germination of oat and pearl millet seeds (Table 2) was not significantly depressed except by the extract from the highest compost rate (320 g) and, in fact, there was improved germination where extracts from 40 to 80 g of compost were used. However, turnip seeds under the

conditions of this experiment were not tolerant of the two highest rates of compost and radish seed germination was depressed greatly at the 80 g compost rate.

Seedling growth of all species increased in the extracts from 10 to 80 g of compost as compared to distilled water. In the 160 g compost extract no radicles developed on turnip seedlings. The extracts were not analyzed for plant nutrients and no attempt was made to determine if a phytotoxic compound was present so no explanation is offered for these beneficial or detrimental effects.

Oat foliage yields and nutrient uptake are presented in Table 3. The highest yield was from plants grown in the 512-ton compost treatment. Nitrogen uptake by the oat plants was much higher from the 512-ton compost treatment than from the other treatments. The lack of significant increase in N uptake by oat plants growing in the 2, 8, and 32 tons/ha treatments indicated that N in the compost was probably diverted to supply the needs of the microbial population. Phosphorus uptake was significantly higher in plants from the two highest rates of compost. As with N uptake, K uptake was greatest in the highest compost rate.

Turnip foliage growth (Table 4) was increased greatly in the three highest compost treatments. Nitrogen deficiency sympotoms-light green color, changing to yellow with age-appeared in all of the other three treatments. On the other hand, turnip plants growing in the 512-ton compost treatment exhibited striking phytotoxic effects which were not identified. The symptoms were not the usual stunting and blue-green color attributable to salt injury, but there was a spiraling in the older leaves which progressed until the leaf cohered into a thin, stem-like appendage.

There was no discoloration in the affected leaves or in the rest of the plant. Nitrogen, P, and K uptake was significantly greater in the turnip plants grown in the three highest rates of compost. Increased yield and N uptake by turnip plants grown in the 32-ton compost treatment indicated that the soil microbial population was releasing N for higher plants utilization. At that time the compost had been in the soil for 6 months.

Radish foliage yields (Table 5) were significantly higher in the 128-and 512-ton compost treatments. Yields in the 2-and 32-ton compost treatments were significantly lower than the control and the 8-ton treatment yielded the same as the control. Here again, N deficiency symptoms appeared in the control and the three lowest compost treatments. There were no indications of phytotoxic effects manifested by any radish plant. The uptake of N, P, and K was significantly greater in plants grown in the 128-and 512-ton compost treatments as compared to plants grown in the other treatments. The low N uptake by plants from the three lowest compost treatments was further evidence of microbial competition for available N.

Pearl millet yields (Table 6) in the 512-ton compost treatment were over two times the 128-ton compost treatment yields. There were N deficiency symptoms manifested by plants growing in the control and 2-ton compost treatments; however, none of the symptoms was severe. There were no recognizable phytotoxic symptoms manifested by any of the pearl millet plants growing in the 512-ton compost treatment. Potassium uptake was of particular interest, as the plants in that treatment removed over 50 times the amount of K removed by the control plants. Potassium deficiency should have developed in the plants growing in the control pots; however, no symptoms were manifested.

As shown in Tables 7 and 8, the two highest rates (128 and 512 tons/ha) of compost increased significantly soil P, K, Ca, Mg, TSS, pH, CEC, and water-holding capacity. In addition, the soil at the end of this experiment appeared to have better structure where the two highest rates of compost were added.

Field. The oat seeds germinated normally in all pots; however, seeds in soil containing the highest rate of compost (512 metric tons/ha) were from 3 to 5 days later than the other seeds in germinating. For the first few weeks, oat seedlings in all pots grew satisfactorily with no indications of nutrient deficiencies. When the seedlings were 6 to 7 weeks old, N deficiency symptoms--yellowish green to yellow leaves and purplish green stems-- began to appear in the control pots and the symptoms increased in severity as growth continued. In addition, N deficiency symptoms were observed after the first cutting (at 12 weeks of age) in the pots containing 2 and 8 tons/ha of compost; however, plants in those pots never developed the severe N deficiency symptoms noted in the control pots. No visual evidence of other nutrient deficiencies were discernible, but other deficiency symptoms would likely have been masked by the N deficiency symptoms.

Total yields of oat foliage from two cuttings (Table 9) were increased signigicantly over the control by all treatments, and yields increased progressively within the compost treated soil as the amount of compost applied increased. The highest yield (52 g) was obtained from the highest rate of compost. Plant growth was, no doubt, a function of the added N available to the plants (168 mg in the lowest rate of compost up to 43 g in the highest rate, and 12.23 g, 2.96 g, 5.91 g, and 1.40 g in the sludge,

cow manure, chicken manure, and 10-10-10 treatments, respectively).

Nitrogen uptake by the oat plants (Table 9) was significantly increased by all treatments except where the three lowest rates of compost were applied. Frequently, plants suffering under a deficiency of a particular nutrient will contain a relatively high concentration of that nutrient. This was true of the oat plants from the control pots which contained 2.58 percent N (average of two cuttings) as compared to 2.29 percent, 2.07 percent, 1.83 percent, 2.04 percent, 2.54 percent, 3.55 percent, 1.86 percent, 3.27 percent, and 2.24 percent N in plants from the other pots, as listed from top to bottom in Table 9. The decrease in N content of plants grown in the first three compost treatments may have resulted from microbial competition as soil microbes satisfy their needs before higher plant species. With regard to other nutrients, only the plants grown in the two lowest rates of compost failed to show significantly higher uptake than the control plants with the noticeable exception of K and Mn uptake from the sludge treatment, which was quite low in both K an Mn.

Yields of fresh radish roots and oven-dry tops (Table 19) were greatly increased where the highest rate of compost was applied. Sewage sludge and chicken manure were the only other materials that produced significantly higher yields than the control. In fact, radish plants from all of the other treatments, except cow manure, yielded lower than control plants. A large part of this negative response was doubtless caused by the removal of N by the oat plants. In addition, some added N was certainly lost through leaching. However, neither explanation applied fully to the reduced yields in pots that had received 128 tons/ha of compost. We can only conjecture that

increased microbial activity in those pots deprived the radish plants of necessary N.

The uptake of plant nutrients by radish tops (Table 19) followed the same trend as yields where significant differences were concerned. However, there was one outstanding exception in that K uptake was greatly curtailed where sewage sludge was applied. The low K content (0.9%) in plants from the sewage sludge treatment, as compared to 0.16 percent K in control plants, indicated that there was a soil K deficiency. Typical N deficiency symptoms-small, yellow leaves and small roots-were prevalent in the first four rates of compost and in the cow manure, 10-10-10, and control treatments. In addition, N uptake by radish plants in those treatments was further evidence of a deficient N supply.

The effects of treatment on some soil measurements (Table 11) were interesting in several respects. Soil pH averaged 6.9 but as pH was not significantly affected by treatment those data are not included. Water-holding capacity, as measured by moisture equivalents, was increased significantly only by the 128-and 512-ton rates of compost, whereas cation exchange capacity was increased significantly only by the 512-ton rate of compost. The two highest total soluble salts and Ca contents were measured in soil which had received 128 and 512 tons/ha of compost. Phosphorus content was increased significantly over the control by all treatments except the two lowest compost rates. The relatively low K content of sewage sludge was again emphasized by the small increase in soil K.

It was quite evident through visual observation, plant yield measurements, and plant and soil analyses that the 512-ton rate of garbage compost was

superior to all other treatments. However, such a high rate, especially in an initial application, is uneconomical except for a few speciality crops or on areas as golf courses, lawns, home gardens, etc.

Microbiological. In the soil microbial population studies, a rapid increase in relative bacterial numbers was obtained during the first 2 days. A rapid drop in bacterial numbers occurred by the 4th day (Figure 1). This drop was followed by a general leveling of the population in the 1- and 5-g treatments. The same initial trend occurred in the 10-g treatment. However, the numbers increased again by the 6th day, then gradually decreased.

An increase in CO_2 evolution was obtained as the levels of each organic material were increased (Figure 3). This increase in CO_2 evolution was not the same for each of the four materials. The rate of increase was faster for sewage sludge and chicken manure and slower for cow manure. There was slightly less CO_2 evolved from chicken manure than from sewage sludge. This was true at all levels. Carbon dioxide evolved from chicken manure and sewage sludge at the 10-g level was 99 percent and 115 percent greater than cow manure and 44 percent and 55 percent greater than garbage compost. At this same level, CO_2 evolution from garbage compost was 28 percent more than cow manure. Municipal refuse contains a large percentage of cellulose, sugars, and starches and sugars and starches should be readily decomposed by microorganisms. In animals, the quality of feed, age, and condition of the animal influence the amount of cellulose or crude fiber left in the feces. Because partial decomposition has taken place in the animal, a larger percentage of more resistant compounds should exist. Therefore, one would expect cow manure to be more resistant to soil microbial attack than garbage

compost. This should be reflected in a reduction of CO_2 evolved. Results obtained indicated significantly less CO_2 was evolved from treatments containing cow manure than garbage compost. On the other hand, chicken manure and sewage sludge contain a higher percentage of N and easily decomposable compounds. Thus one would expect these materials to decompose readily after being added to soil. When total CO_2 evolution from the treatments was compared, a highly significant interaction was observed between materials and level applied. Separate regression equations were obtained for each material and the slopes of regressions lines were significantly different. The relationship between treatment levels and total CO_2 evolved was linear in all cases. There was no significant difference detected in total CO_2 for all levels used in this study for chicken manure and sewage sludge. At all levels, CO_2 production for chicken manure and sewage sludge was significantly greater than that obtained with cow manure or garbage compost, there was no significant difference at the lower levels. However, garbage compost became significantly different from cow manure between the 6-and 8-g level. At the 2-g level, the amount of NO_3-N produced was from highest to lowest chicken manure, sewage sludge, cow manure, and garbage compost. At this low level, there was approximately 120 percent more NO_3-N produced from chicken manure than from sewage sludge and 227 percent more than from cow manure. However, a rapid decrease occurred in NO_3-N production when levels of chicken manure and sewage sludge were increased (Figure 4). This decrease was probably the result of an inhibitory effect on nitrification by the high levels of N added. At the 2-g level, 528 and 1,092 ppm N, respectively, were added when chicken manure and sewage sludge were used. Nitrate nitrogen in the cow manure treatments increased linearly as levels of material were increased. Very little nitrification occurred in the garbage compost treatments. This was probably due to rapid immobilization of N by microflora during decompostiion of the compost. A highly significant interaction was obtained between materials and level applied.

In the study involving 11 levels of garbage compost, there was a progressive increase in amounts of CO_2 evolved as the amount of compost was increased (Figure 5). It was evident that an increase in the amount of compost added increased the total amount of CO_2 evolved and that the upper limit had not been reached. A highly significant relationship was detected between levels of compost used.

In the investigation involving the combination of materials, CO_2 evolution increased as levels of materials were increased (Figure 6). This was true for all treatments. As in the single material study, the rate of increase was faster for sewage sludge and chicken manure and slower for cow manure. At the highest level of application, CO_2 evolution from chicken manure and sewage sludge was 30 and 55 percent, respectively, more than cow manure. An interesting observation was noted when the results of this study were compared with results obtained from the single material study (Figure 3). When CO_2 values from the garbage compost were added to those of cow manure, chicken manure, or sewage sludge and compared with those obtained in this study, very little difference was obtained. This indicated that combining materials had little effect on rate of decomposition. Analyses of variance indicated that for total CO_2 evolved, the effects of material and rate are independent. The total CO_2 evolved was found to be significantly less for cow manure than for the other two materials. No significant difference was detected between chicken manure and sewage sludge. For NO_3-N (Figure 7), the relationship of chicken manure to sewage sludge was somewhat similar to that observed with single materials (Figure 4). However, production was greater and occurred at a higher level than with single materials. This

was the reverse from the results obtained in the second study (Figure 4) which indicated that the available N in the cow manure may have been immobilized by the microflora in the decomposition of the combined materials. These results also illustrated the modifying influence of compost in reducing the excessive amounts of nitrogen available for nitrification. For NO_3-N the interaction between levels of materials was found to be significant.

In general, the relative numbers of fungi in garbage compost increased with time of incubation and bacteria decreased with time of incubation. Little nitrification occurred in the garbage compost treatments; nitrification rate decreased rapidly as levels of chicken manure and sewage sludge were increased above the 2-g level; chicken manure and sewage sludge decomposed at a faster rate than garbage compost or cow manure; and garbage compost decomposed at a faster rate than cow manure.

St. Petersburg Compost

Greenhouse. Cranberry beans grew normally in all of the treatments with no evidence of nutrient deficiences or phytotoxic effects in any plants. There were no significant differences among treatments with respect to seedling weights (Table 12). However, compost applied at the 16-ton rate and higher resulted in significantly more bean pods and fresh bean weights than either control treatment.

Uptake of N and K by bean seedlings was not significantly affected by treatment (table 13); however, K uptake was significantly higher in seedlings removed from the 64-ton rate as compared to the controls. In contrast, mature beans removed significantly greater amounts of N-P-K from soil treated with 16tons/ha and higher of compost (Table 14).

The oat plants grew normally with no indications of nutrient deficiencies, but yields and N-P-K uptake (Table 15) showed evidence that these elements were in short supply in the control (10-10-10 and no fertilizer) pots. Oat plants growing in the presence of 16 tons/ha and higher of compost significantly outyielded the controls and N-P-K uptake was much greater from the 32-and 64-ton compost applications than from the controls. It was quite evident that the residual compost supplied adequate amounts of N-P-K for the oat plants and at the two highest rates (32 and 64 tons/ha) there was luxury consumption of K.

After the oat plants were harvested, additional compost or 10-10-10 fertilizer was added in the original amount. After 7 days, tomato seedlings transplanted from vermiculite were well established and growing in all pots except where 32 and 64 tons/ha of compost were applied. The seedlings in the 32-ton treatment survived, but did not start growing until 21 days from transplanting. In the 64-ton treated soil three seedlings died and were replaced, and growth did not resume in those pots until the seedlings had been in the soil for over 30 days. This compost contained some chemical that was highly toxic to tomato; however, we were unable to determine the responsible toxicant.

Yields of tomato plant material (Table 16) from the 10-10-10 control pots were over twice the yields from any other pot. The yields from the 64-ton rate of compost were reduced drastically as indicated above. The only compost treatment that outyielded significantly the no-fertilizer control was the 8-ton rate. Uptake of N-P-K was much greater from the mineral fertilizer than from the compost. There was no doubt that the tomato plants in the no-fertilizer control suffered from K deficiency as those plants contained only 0.85% K which was definitely below the deficiency level.

Compost applications to Arredondo sand increased soil pH, as compared to the no fertilizer control, whereas 10-10-10 fertilizer decreased the pH (Table 17). Soluble salts were increased by the two highest compost applications (32 and 64 tons/ha); however, it is doubtful that these levels were high enough to be harmful to plant life. The TSS levels were surely much higher in all treatments soon after compost or fertilizer applications, but several liters of water added for plant use had moved the salts out of the soil. Soil levels of P,K, Ca, and Mg were greatly increased by two compost applications of 4 to 64 tons/ha. Potassium levels in the control pots were much lower than in any of the compost treated pots.

Fairfield Compost

Greenhouse. The first sorghum seeds planted germinated satisfactorilly in pots and the plants grew normally without manifesting any deficient or toxic symptoms. Sorghum plants that were growing in soil containing the two highest rates of compost (32 and 64 tons/ha) and 10-10-10 fertilizer produced seedheads 7 days before the two lowest rates of compost (8 and 16 tons/ha) and 14 days before the no-fertilizer control. Average plant height at maturity was greatest in sorghum from the 32-ton rate of compost (704 mm) and least from the no-fertilizer control (379 mm).

Sorghum yields were significantly increased by all compost applications as compared to no fertilizer (Table 18). However, only the 64-ton compost rate outyielded the 10-10-10 fertilizer control. Uptake of N-P-K was also significantly greater in plants grown where compost was applied as compared to no fertilizer. Uptake of N and K from the compost treated soil was almost linear from the low to the highest rate.

The second sorghum crop was normal in all treatments except where no fertilizer or compost was applied. As shown in Table 19, yields of sorghum

plants grown in the unfertilized soil were much lower than yields from the other treatments and greatly reduced as compared to the first crop (1.4 g versus 11.2 g). This indicated that the first crop removed a large portion of the available plant nutrients from the soil leaving very little for the second crop. On the other hand, residual plant nutrients plus the additional compost or fertilizer greatly benefited plants growing in the other treatments as shown by plant yields and N-P-K uptake.

Gainesville Compost

Field. The phosphate mining process involves a procedure in which the phosphate is removed from the matrix through flotation. After the phosphate is removed, there remains two waste products--phosphate "slimes" and sand tailings--which are of major concern to the industry as they present tremendous problems of disposal and land reclamation. The sand tailings are pumped onto mined out areas to depths of 20 feet and higher, allowed to drain, and planted to suitable vegetation. This material is a coarse sand, quite low in available plant nutrients (pH 7.5, and containing 36 ppm P, 5 ppm K, 223 ppm Ca, and 36 ppm Mg extracted in NH_4OAc at pH 4.8), and with little cation exchange capacity or water-holding capacity.

The first crop, sorghum, planted in this experiment was slow in becoming established and showed evidence of nutrient deficiencies almost continuously from seedling stage to maturity. Torrential rains, during the 4th and 5th weeks from planting induced severe N deficiency symptoms in all plots. Therefore, NH_4NO_3 was applied as a sidedressing to the sorghum growing in plots which received 10-10-10. Seedhead yields in this first crop (Table 20 were significantly increased where compost plus 10-10-10 was applied as compared to 10-10-10 above.

However, yields from plots which received only compost were negligible. Yields from the first crop of oats were also increased greatly where compost plus 10-10-10 was applied. Oat seeds germinated satisfactorily in the plots containing residual compost only, but 100 percent of the seedlings died shortly after germination. The cause of death was not determined; however, it was doubtless brought about by severe N deficiency. The second crop of sorghum appeared much healthier than the first crop and seedhead yields were much greater. Also, the second oat crop was much better than the first crop.

The large increase in sorghum seedhead yields from all plots in the second year as compared to the first year was outstanding. This was particularly noteworthy in the compost only plots. Oat seeds were broadcast on the plots in the first year and were eaten by redwing blackbirds which necessitated replanting. Oat seeds were planted in furrows/plot, 72 cm apart, in the second year. Therefore, yields cannot be compared between years, but the second year yields would certainly have been 3 or 4 times higher under broadcast planting. Again with oats, the increase in yields from compost only plots between years was noteworthy. Bird pilferage during both years prevented oat seed harvests and forced the planting of bird resistant sorghum seed.

The addition of compost plus 10-10-10 to sand tailings resulted in increased K contents of sorghum the first year and increased N-K contents the second year as compared to 10-10-10 alone (Table 21). Compost alone did not provide sufficient N for satisfactory sorghum growth during the first year; however, during the second year N availability was improved considerably. Nitrogen uptake by sorghum during the first year was significantly less in plants growing in compost treated soil than where 10-10-10 alone was applied.

This was reversed during the second year which indicated that residual compost was influencing N availability. Nitrogen determinations in oat foliage (Table 22) also supports this observation.

SUMMARY

Under a strict interpretation of the requirements that an organic material must meet for compost qualification, only the Fairfield material could be so classified. That material had a C/N ratio of 17 as compared to 26 for the Largo compost, 43 for the St. Petersburg compost, and 55 for the Gainesville compost. In addition to a relatively low C/N ratio, the Fairfield compost was pelletized, free of moisture, and agreeable to handle. In contrast, the other composts contained excess moisture and had physical characteristics that made them exceedingly disagreeable to handle. The low soluble salt content (Table 1) of the Fairfield compost and the high soluble salt content of the other three composts must also be considered in rating these materials.

The future of municipal refuse composting depends to a large extent on utilization of the finished product. Our investigations indicated that the compost was beneficial to the soil and that relatively large amounts could be applied without danger to plants. However, we must recognize that low N content and high soluble salt content present problems that must be overcome. In both instances the soil microbial population and climatic conditions will alleviate detrimental effects in time, by narrowing the C/N ratio and by leaching soluble salts below the root zone.

We are cognizant of the fact that laboratory and greenhouse investigations are most useful in evaluating materials as the composts used in our studies.

However, the laboratory or greenhouse cannot substitute for actual field conditions. Research in the field was only begun and it must continue in order to complete the picture.

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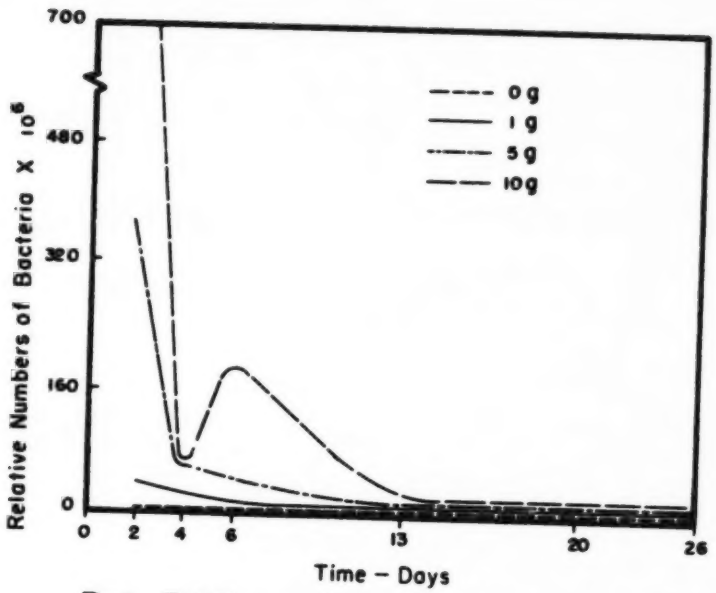

Fig. 1. Relative numbers of bacteria and actinomyces per gram of a mixture of finely ground garbage compost and Arredondo fine sand.

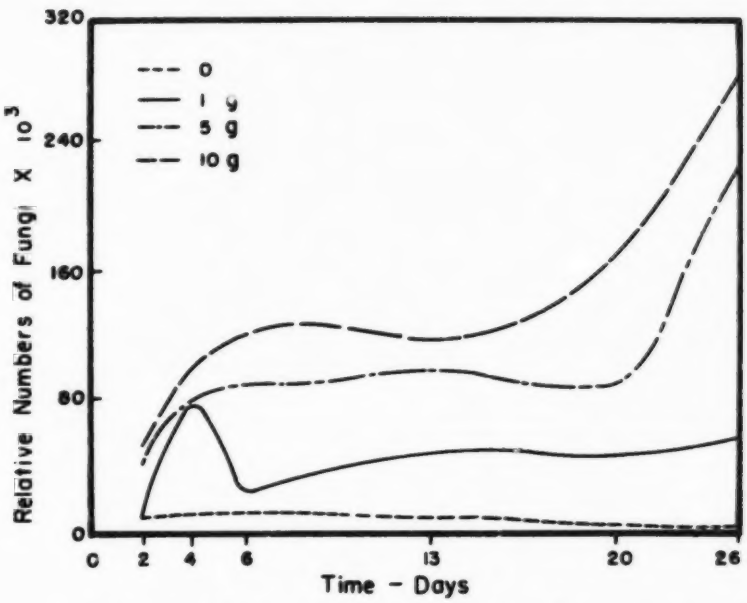

Fig. 2. Relative numbers of fungi per gram of mixtures of finely ground garbage compost and Arredondo fine sand.

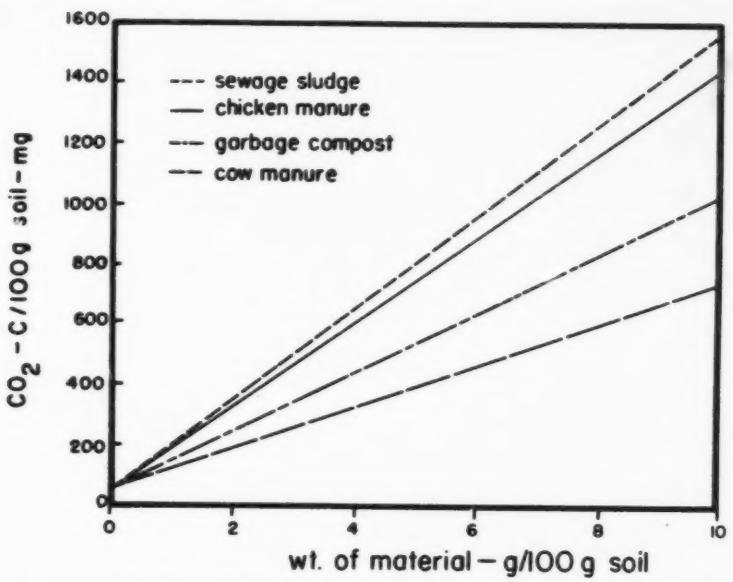

Fig. 3. Total amount of CO_2-C evolved from mixtures of Arredondo fine sand and organic materials over a period of 65 days.

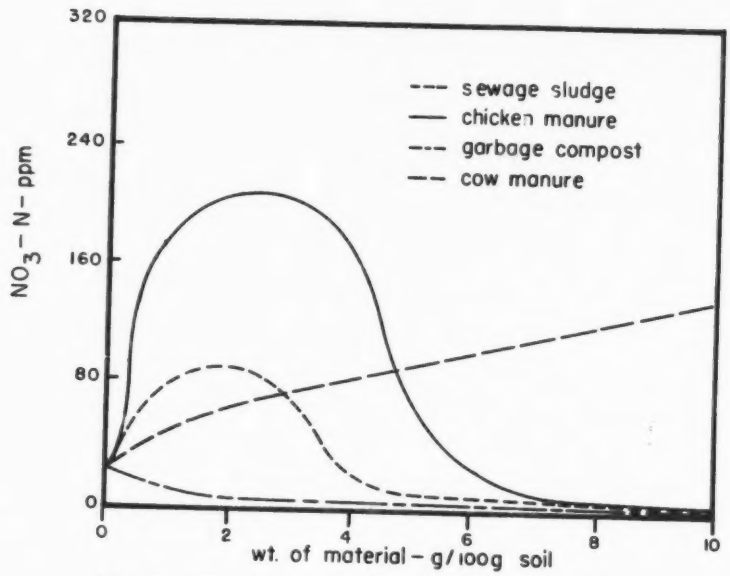

Fig. 4. Nitrate N produced from mixtures of Arredondo fine sand and organic materials after 65 days.

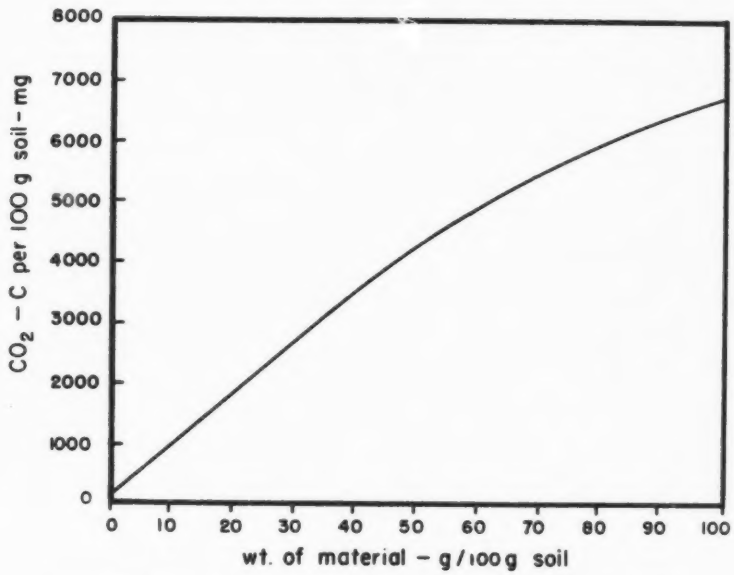

Fig. 5. Total amount of CO_2–C evolved from ground garbage compost mixed with Arredondo fine sand over a period of 101 days.

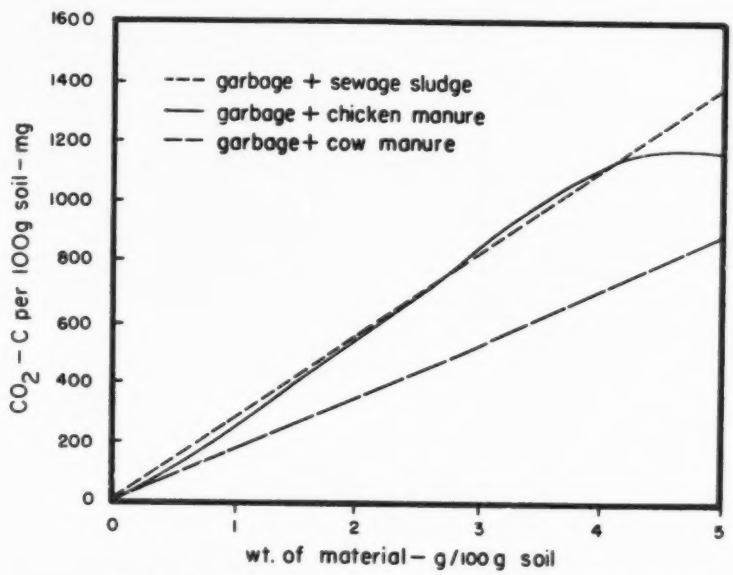

Fig. 6. Total amount of CO_2 – C evolved from mixtures of finely ground garbage compost with cow manure, chicken manure, and sewage sludge mixed with Arredondo fine sand over a 64 – day period.

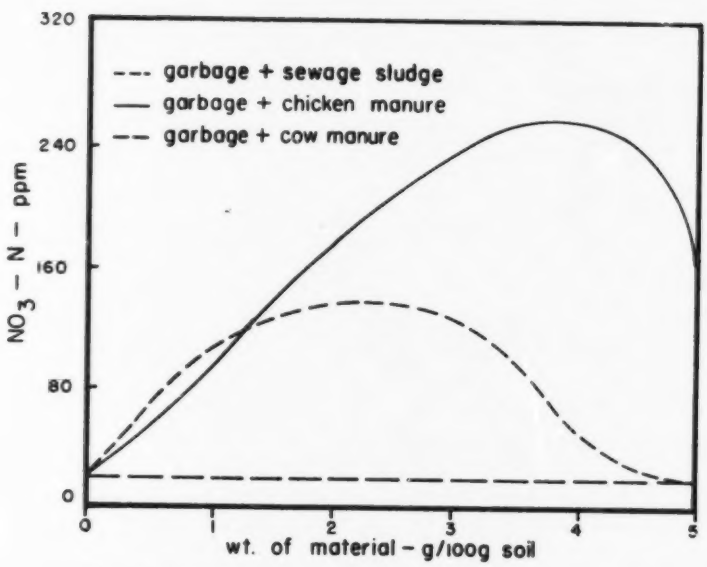

Fig. 7. Nitrate nitrogen produced from combinations of ground garbage with cow manure, chicken manure and sewage sludge mixed with Arredondo fine sand at the end of 64 days.

TABLE 1

CHEMICAL CONSTITUENTS OF ORGANIC MATERIALS USED IN THESE EXPERIMENTS

Material	pH	ash	C	TSS	N	P	K	Ca	Mg	Mn	B	Cu	Zn
		----------	----------	----------	----------	----------	----------	----------	----------	------	------	------	------
		%								ppm			
Cura Compost	7.5	16	33	1.73	0.76	0.17	0.30	0.99	0.07	106	-	29	196
Fairfield Compost	5.7	-	39	0.02	2.27	0.45	0.20	0.01	-	8	16	-	294
Largo Compost	6.9	44	31	2.30	1.20	0.26	0.38	1.30	0.07	130	25	125	250
Gainesville Compost	6.9	42	32	2.15	0.58	0.23	0.21	2.14	0.12	140	40	-	540
Milorganite Compost	4.1	27	-	2.20	5.46	0.28	0.34	0.30	0.16	23	5	90	180
Cow Manure	6.7	50	-	4.40	1.32	0.52	2.52	1.29	0.27	81	6	16	38
Chicken Manure	7.2	33	-	4.05	2.64	0.48	1.80	1.85	0.38	133	17	32	196

TABLE 2

EFFECTS OF COMPOST/WATER EXTRACTS ON SEED GERMINATION AND SEEDLING LENGTH AFTER 5 DAYS

Compost	Oats		Turnip		Radish		Millet	
g	%	mm	%	mm	%	mm	%	mm
0	92	123	96	48	96	72	82	74
10	94	151	100	82	100	100	82	90
20	92	149	96	91	100	98	80	80
40	98	151	93	87	96	90	91	91
80	99	131	84	77	56	82	88	99
160	96	74	40	14	16	17	78	70
320	41	29	0	0	0	0	45	37
L.S.D. 5%	5	20	15	7	5	18	5	12
1%	7	25	17	9	7	20	7	16

TABLE 3

YIELDS AND N, P, AND K UPTAKE BY OAT FOLIAGE GROWN IN LEON FINE SAND

Material applied	T/ha	Oven-dry	N	P	K
		g/pot	----------mg/pot---------		
None	0	1.6	57	3	92
Compost	2	2.2	66	3	88
Compost	8	2.6	61	3	112
Compost	32	1.9	63	4	104
Compost	128	2.4	87	6	128
Compost	512	3.4	142	9	173
L.S.D.	5%	0.5	20	1	35
	1%	0.7	30	2	42

TABLE 4

YIELDS AND N, P, K UPTAKE BY TURNIP FOLIAGE GROWN IN LEON FINE SAND

Material applied	T/ha	Oven-Dry	N	P	K
		g/pot	----------mg/pot----------		
None	0	1.7	34	5	31
Compost	2	2.9	54	6	50
Compost	8	2.7	54	7	54
Compost	32	4.3	86	12	103
Compost	128	6.0	113	21	168
Compost	512	5.2	282	18	295
L.S.D.	5%	1.5	25	3	25
	1%	2.0	30	5	30

TABLE 5

YIELDS AND N,P, K UPTAKE BY RADISH FOLIAGE GROWN IN LEON FINE SAND

Material applied	T/ha	Oven-dry	N	P	K
		g/pot	--------mg/pot--------		
None	0	4.8	123	8	89
Compost	2	3.9	112	6	56
Compost	8	4.2	103	8	90
Compost	32	3.1	87	8	133
Compost	128	7.5	192	18	355
Compost	512	7.0	237	22	367
L.S.D.	5%	1.4	30	5	125
	1%	1.8	35	6	150

TABLE 6

YIELDS AND N, P, K UPTAKE BY PEARL MILLET FOLIAGE GROWN IN LEON FINE SAND

Material applied	T/ha	Oven-dry	N	P	K
		g/pot	----------mg/pot--------		
None	0	7.8	107	12	23
Compost	2	7.6	113	10	45
Compost	8	9.2	125	16	34
Compost	32	11.8	146	16	86
Compost	128	18.2	203	37	597
Compost	512	39.1	305	57	1,230
L.S.D.	5%	6.0	65	8	67
	1%	8.5	77	10	79

TABLE 7

EFFECTS OF TREATMENT ON SOIL P,K,Ca, Mg, TOTAL SOLUBLE SALTS, AND pH OF LEON FINE SAND

Material applied	T/ha	P	K	Ca	Mg	TSS	pH
		ppm					
None	0	1	7	738	16	287	6.2
Compost	2	3	9	669	16	229	6.0
Compost	8	3	8	684	16	229	6.0
Compost	32	3	9	882	16	258	6.1
Compost	128	6	13	1,165	42	607	6.4
Compost	512	10	17	1,682	79	1,512	6.5
L.S.D.	5%	2	4	158	11	131	.1
	1%	3	5	215	15	178	.2

TABLE 8

EFFECTS OF TREATMENT ON CATION EXCHANGE CAPACITY AND WATER-HOLDING CAPACITY OF LEON FINE SAND.

Material applied	T/ha	CEC	Soil Moisture (%)		
		meg/100g	1/10 atm	1/3 atm	15 atm
None	0	3.67	6.42	4.28	3.84
Compost	2	3.70	6.45	4.18	4.00
Compost	8	3.78	6.65	4.39	3.96
Compost	32	3.90	7.34	4.78	4.36
Compost	128	4.81	8.15	5.91	5.52
Compost	512	7.14	10.79	8.62	8.10
L.S.D.	5%	.48	.47	.37	.35
	1%	.64	.63	.50	.46

TABLE 9

INFLUENCE OF TREATMENT ON YIELD AND NUTRIENT

UPTAKE BY OATS GROWN ON LEON FINE SAND

Material	Amount applied	Yield	N	P	K	Ca	Mg	Mn	B	Cu	Zn
	Metric tons/ha	g/pot	mg/pot								
Garbage Compost	2	26	604	36	435	134	58	1.4	0.3	0.4	1.7
" "	8	28	594	39	560	135	57	1.8	0.3	0.5	1.8
" "	32	36	678	53	1015	166	80	5.1	0.5	0.6	3.1
" "	128	49	1011	116	1865	231	126	14.9	1.1	1.0	5.7
" "	512	52	1170	101	1880	245	110	16.0	2.6	1.1	4.4
Sewage sludge	32	42	1405	157	413	375	112	2.9	0.5	0.9	4.4
Cow manure	32	45	896	138	1955	151	89	3.4	0.4	0.6	4.0
Chicken manure	32	45	1443	150	1736	234	100	5.0	0.6	0.6	4.0
10-10-10+Mg, Mn, Cu, Zn, B	2	46	1051	76	1000	218	116	8.6	0.7	0.9	5.4
Control	-	19	494	22	215	111	39	0.8	0.2	0.3	1.0
L.S.D.	5%	6	229	23	432	50	26	3.5	0.4	0.2	1.4
	1%	8	311	32	590	68	35	4.8	0.6	0.3	1.9

TABLE 10

INFLUENCE OF TREATMENT ON RADISH YIELDS AND NUTRIENT UPTAKE BY RADISH TOPS GROWN ON LEON FINE SAND

Material	Amount applied	Yield: Fresh roots	Yield: Oven-dry tops	N	P	K	Mn	Zn	Cu
	Metric tons/ha	------g/pot-------		----------mg/pot----------					
Garbage Compost	2	27	2.0	56	56	24	.05	0.2	.02
" "	8	36	2.3	59	62	25	.07	0.3	.02
" "	32	34	1.9	50	55	25	.07	0.2	.02
" "	128	39	2.1	62	84	47	.11	0.3	.02
" "	512	187	9.4	375	263	467	.54	3.0	.16
Sewage sludge	32	113	8.9	260	695	65	.43	1.7	.12
Cow manure	32	67	3.2	99	126	61	.17	0.3	.04
Chicken manure	32	151	6.6	204	304	126	.33	0.7	.07
10-10-10+Mg, Mn, Cu, Zn, B	2	43	2.7	66	82	30	.17	0.4	.03
Control	-	50	3.6	100	105	35	.08	0.5	.04
L.S.D.	5%	37	1.0	37	72	79	.10	0.3	.03
	1%	50	1.3	51	90	108	.13	0.4	.04

TABLE 11

INFLUENCE OF TREATMENT ON SOME PHYSICAL AND CHEMICAL PROPERTIES OF LEON FINE SAND

Material	Amount applied	ME	CEC	TSS	Ca	P	K	Mg
	Metric tons/ha	%	meg/100g	ppm				
Garbage Compost	2	5.19	4.05	272	825	2.0	10	26
" "	8	5.33	4.01	297	860	2.0	15	24
" "	32	5.65	4.27	569	915	3.5	19	32
" "	128	6.98	4.90	1035	1188	7.5	95	54
" "	512	11.54	8.28	1663	1981	11.0	223	104
Sewage sludge	32	5.57	4.51	256	690	11.0	12	38
Cow manure	32	5.73	4.27	674	986	12.3	133	60
Chicken manure	32	5.33	4.55	296	895	16.5	23	60
10-10-10-+ Mg, Mn, Cu, Zn, B	2	5.60	4.84	641	766	4.0	12	39
Control	-	5.83	4.67	171	785	1.8	10	20
L.S.D.	5%	.41	.66	330	140	0.4	60	14
	1%	.55	.90	448	190	0.5	81	19

TABLE 12

YIELDS OF BEAN PLANT MATERIAL GROWN IN ARREDONDO SAND CONTAINING "CURA" COMPOST

Material	Rate	Seedlings	Pods/pot	Fresh Beans	Oven-dry Plants
	tons/ha	g/pot	No./pot	g/pot	g/pot
Cura	1	4.0	6	9.8	5.9
"	2	4.2	8	15.8	6.3
"	4	4.4	7	16.2	6.7
"	8	4.4	6	14.4	7.0
"	16	4.9	9	21.2	8.2
"	32	5.0	10	18.9	7.7
"	64	6.0	11	20.4	8.6
10-10-10	1	4.9	5	12.7	6.2
None	-	5.0	6	13.5	6.2
L.S.D.	5%	N.S.	3	5.0	2.1
	1%	N.S.	4	6.7	N.S.

TABLE 13

UPTAKE OF N,P, AND K BY IMMATURE BEANS
PLANTS GROWN IN ARREONDO SAND CONTAINING "CURA" COMPOST

Materials	Rate	N	P	K
	Tons/ha		mg/pot	
Cura	1	197	28	104
"	2	199	28	97
"	4	220	31	108
"	8	223	32	121
"	16	240	34	147
"	32	238	30	149
"	64	296	34	262
10-10-10	1	253	34	148
None	-	207	31	101
L.S.D.	5%	N.S.	N.S.	58
	1%	N.S.	N.S.	79

TABLE 14

UPTAKE OF N,P, AND K BY MATURE BEAN
PLANTS GROWN IN ARREDONDO SAND CONTAINING "CURA COMPOST

Material	Rate	N	P	K
	Tons/ha		mg/pot	
Cura	1	104	14	76
"	2	105	17	78
"	4	117	21	83
"	8	111	22	105
"	16	155	25	150
"	32	126	22	146
"	64	147	25	225
10-10-10	1	112	15	95
None	-	90	15	58
L.S.D.	5%	38	8	34
	1%	N.S.	N.S.	46

TABLE 15

YIELDS AND UPTAKE OF N,P, AND K BY OAT
PLANTS GROWN IN ARREDONDO SAND CONTAINING "CURA" COMPOST

Materials	Rate	Oven-dry	N	P	K
	Tons/ha	g/pot	----------mg/pot----------		
Cura	1	6.7	70	26	92
"	2	6.3	68	26	84
"	4	6.0	61	27	75
"	8	6.4	66	30	101
"	16	7.8	70	33	101
"	32	8.2	92	40	179
"	64	8.1	93	44	225
10-10-10	1	5.7	51	26	92
None	-	5.5	62	25	70
L.S.D.	5%	1.1	13	4	25
	1%	1.4	18	6	34

TABLE 16

YIELDS AND UPTAKE OF N,P, AND K BY TOMATO PLANTS
GROWN IN ARREDONDO SAND CONTAINING "CURA" COMPOST

Material	Rate	Oven-dry	N	P	K
	Tons/ha	g/pot	----------mg/pot---------		
Cura	1	6.1	96	32	62
"	2	6.4	90	21	64
"	4	6.2	90	22	70
"	8	7.6	101	25	113
"	16	4.9	67	22	118
"	32	4.7	55	24	151
"	64	1.9	29	10	69
10-10-10	1	15.2	197	34	227
None	-	5.8	97	20	50
L.S.D.		1.7	18	7	23
		2.4	25	9	31

TABLE 17

INFLUENCE OF TREATMENT ON SOME CHEMICAL PROPERTIES OF ARREDONDO SAND

Material	Rate	pH	TSS	P	K	Ca	mg
	Tons/ha		ppm				
Cura	1	6.60	415	8	97	751	77
"	2	6.60	394	8	131	918	86
"	4	6.60	545	12	235	1315	105
"	8	6.65	435	15	322	1645	115
"	16	6.70	495	19	365	1865	128
"	32	6.60	746	21	442	2160	144
"	64	6.80	1288	25	590	2798	191
10-10-10	1	6.05	543	7	41	516	68
None	-	6.50	417	6	12	354	59
L.S.D.	-	0.10	189	2	49	235	25
	-	0.13	257	3	66	320	34

TABLE 18

YIELDS AND N,P, AND K UPTAKE BY THE FIRST SORGHUM PLANTS GROWN IN ARREDONDO SAND CONTAINING FAIRFIELD COMPOST

Materials	Rate	Oven-dry	N	P	K
	Tons/ha	g/pot	----------mg/pot---------		
None	-	11.2	102	33	55
Compost	8	16.7	194	58	85
"	16	20.6	269	71	117
"	32	24.8	383	79	171
"	64	26.0	579	77	254
10-10-10	2	22.3	412	67	368
L.S.D.	5%	3.0	78	9	31
	1%	4.2	108	13	43

TABLE 19

YIELDS AND N,P, AND K UPTAKE BY THE SECOND SORGHUM PLANTS GROWN IN ARREDONDO SAND CONTAINING FAIRFIELD COMPOST

Material	Rate	Oven-dry	N	P	K
	Tons/ha	g/pot	---------mg/pot-------		
None	-	1.4	38	7	5
Compost	8	12.1	124	40	48
"	16	18.9	183	47	86
"	32	31.5	312	68	178
"	64	39.6	673	82	352
10-10-10	2	34.4	504	62	585
L.S.D.	5%	3.5	82	9	21
	1%	4.9	114	13	29

TABLE 20

YIELDS OF SORGHUM SEEDHEADS AND OAT FOLIAGE
GROWN IN PHOSPHATE MINE TAILINGS CONTAINING COMPOST

Compost 10-10-10 ----Tons/ha-----		Sorghum (g/plot) 1968-'69	Sorghum (g/plot) 1969-'70	Oats (g/plot) 1968-'69	Oats (g/plot) 1969-'70
0	1	290	626	2086	1022
35	1	492	886	2723	1520
70	1	540	1248	2674	1838
30	0	8	151	0	86
70	0	28	432	0	130
L.S.D.	5%	124	118	387	304
	1%	174	174	542	424

TABLE 21

EFFECTS OF COMPOST ON N-P-K CONTENTS OF SORGHUM PLANTS GROWING IN PHOSPHATE SAND TAILINGS

Compost	10-10-10	1968-'69(%)			1969-'70(%)		
----Tons/ha------		N	P	K	N	P	K
0	1	1.51	0.55	0.39	0.82	0.40	1.49
35	1	1.15	0.52	0.87	1.37	0.60	2.57
70	1	1.11	0.43	1.12	1.56	0.67	2.94
35	0	0.84	0.44	1.50	1.36	0.59	2.32
70	0	0.85	0.45	1.94	1.53	0.60	2.65
L.S.D.	5%	0.22	0.07	0.13	0.20	N.S.	0.16
	1%	0.31	N.S.	0.18	0.30	N.S.	0.22

TABLE 22

EFFECTS OF COMPOST ON N-P-K CONTENTS OF OAT PLANTS GROWING IN PHOSPHATE SAND TAILINGS

Compost	10-10-10	1968-'69(%)			1969-'70(%)		
----Tons/ha--------		N	P	K	N	P	K
0	1	0.66	0.38	1.07	0.65	0.33	1.47
35	1	0.87	0.42	0.97	0.75	0.34	1.37
70	1	0.93	0.47	0.95	0.83	0.32	1.28
35	0	-	-	-	1.07	0.45	1.25
70	0	-	-	-	1.10	0.41	1.24
L.S.D.	5%	0.12	0.03	N.S.	0.13	0.07	N.S.
	1%	0.18	0.04	N.S.	0.19	0.08	N.S.

TABLE 23

EFFECTS OF TREATMENT ON SOIL pH, P, K, Ca, AND Mg
IN PHOSPHATE MINE TAILINGS

Compost	10-10-10	pH	P	K	Ca	Mg
----Tons/ha------			----------ppm----------			
0	1	6.5	47	5	235	14
35	1	6.6	42	9	261	16
70	1	6.6	42	8	324	15
35	0	6.5	40	8	300	18
70	0	6.5	41	9	245	16
L.S.D.	-	N.S.	5	N.S.	N.S.	N.S.
	-	N.S.	N.S.	N.S.	N.S.	N.S.

TABLE 24

EFFECTS OF TREATMENT ON SOIL CATION EXCHANGE CAPACITY AND MOISTURE RETENTION+ IN PHOSPHATE MINE TAILINGS

Compost	10-10-10	C.E.C.	Soil Moisture(%)			
Tons/ha		meg/10og	Field*	0.10atm.	0.33atm.	15 atm.
0	1	0.65	3.54	2.17	1.29	1.34
35	1	0.92	4.05	2.62	1.43	1.22
70	1	1.20	3.74	2.70	1.36	1.23
35	0	0.91	3.72	2.17	1.51	1.43
70	0	1.02	4.03	2.61	1.61	1.57
L.S.D.	5%	0.24	0.29	N.S.	0.21	0.24
	1%	0.34	0.40	N.S.	N.S.	N.S.

+ Moisture measurements were made on undisturbed cores in metal tubes 3 cm long and 5.4 cm inside diameter.

* Soil sampled 2 days after about 2.5 cm of rain.